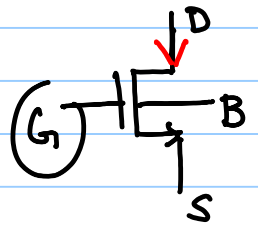
Lecture #7

Note Title 29-01-2019

NMOS

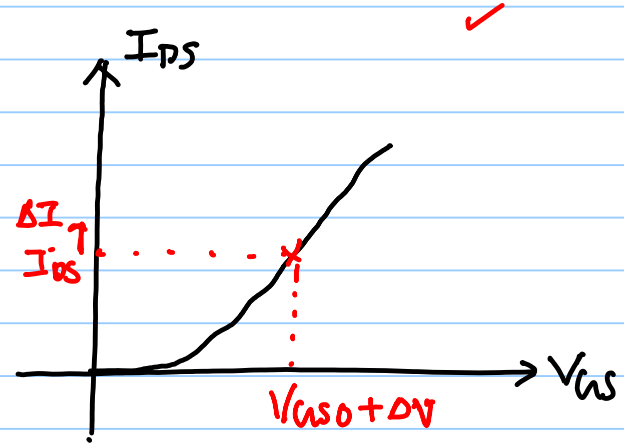


Cut off : $I_{DS} = 0, \quad V_{GS} - V_{th} < 0$

Linear : $I_{DS} = \mu_n C_{ox} \frac{W}{L} \left((V_{GS}-V_{th})V_{DS} - \frac{V_{DS}^2}{2} \right), \quad V_{DS} < V_{GS} - V_{th}$

Saturation : $I_{DS} = \mu_n C_{ox} \frac{W}{2L} \left[V_{GS} - V_{th} \right]^2 (1+\lambda V_{DS}), \quad V_{DS} \geq V_{GS} - V_{th}$

1. Resistor
2. Current source :
3. $\frac{\Delta I_{DS}}{\Delta V_{GS}} = \text{constant}$



$$\Delta I_{DS} = \left(\frac{\partial I_{DS}}{\partial V_{GS}} \right) \cdot \Delta V_{GS}$$

$$= \left(\frac{2 I_{DS}}{V_{GS} - V_{th}} \right) \cdot \Delta V_{GS}$$

$$I_{DS}' = \mu_n C_{ox}\frac{W}{2L}\left[V_{GS} + \Delta V - V_{th}\right]^2$$

$$= \mu_n C_{ox}\frac{W}{2L}\left[(V_{GS}-V_{th})^2 + \Delta V^2 + 2(\Delta V)(V_{GS}-V_{th})\right]$$

$$= I_{DS} + \frac{2I_{DS}}{V_{GS}-V_{th}}\cdot\Delta V + \underbrace{I_{DS}\cdot\left(\frac{\Delta V}{V_{GS}-V_{th}}\right)^2}_{\approx 0}$$

$\Delta V \ll V_{GS}-V_{th}.$

$$\cancel{I_{DS}}+\Delta I_{DS} = I_{DS}' = \cancel{I_{DS}} + \frac{2I_{DS}}{V_{GS}-V_{th}}\cdot\Delta V$$

$$\Delta I_{DS} = \underbrace{\frac{2I_{DS}}{V_{GS}-V_{th}}}_{g_m}\cdot\Delta V$$

Sat:

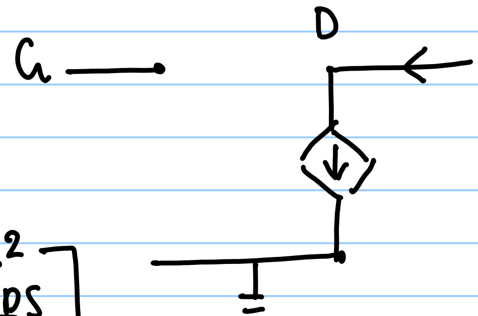
$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}} = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{th}) (1 + \underbrace{\lambda V_{DS}}) \checkmark \quad (1)$$

$$\approx \underbrace{\mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{th})} \checkmark$$

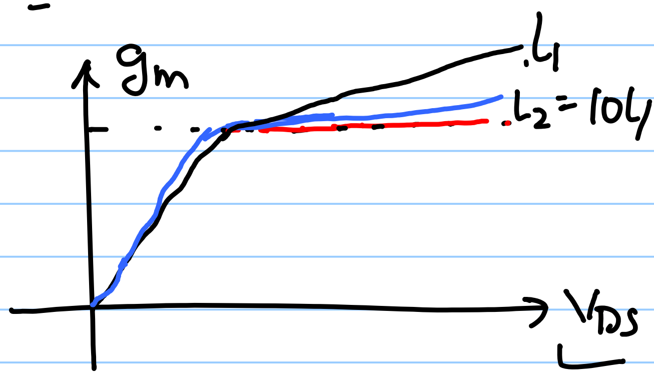
linear

$$g_m = \frac{\partial I_{DS}}{\partial V_{GS}} = \mu_n C_{ox} \frac{W}{L} V_{DS} \checkmark \quad (2)$$

$$I_{DS} = \mu_n C_{ox} \frac{W}{L} \left[(V_{GS} - V_{th}) V_{DS} - \frac{V_{DS}^2}{2} \right]$$



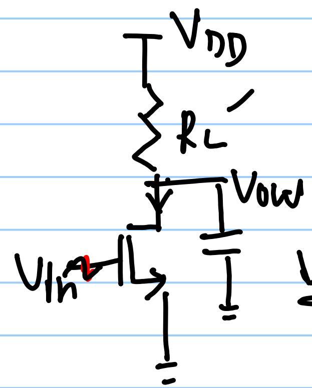
$$\Delta I_{DS} = g_m \cdot \Delta V_{GS}.$$



Sat:

$$g_m = \frac{2 I_{DS}}{(V_{GS} - V_{th})} = \frac{2 I_{DS}}{V_{ov}} \checkmark$$

$$\boxed{\frac{g_m}{I_{DS}} = \frac{2}{V_{ov}}}$$



$$\frac{V_{out}}{V_{in}} = -g_m \cdot R_L$$

$$\frac{g_m}{I_{DS}} = x \rightarrow 1mA. \Rightarrow g_m = x \cdot 1mA$$

$$\frac{g_m}{I_{DS}} = 2x \Rightarrow g_m = 2x \cdot 1mA$$

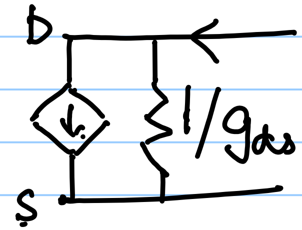
$$\boxed{V_{OV} > 2V_T}$$

Sat:

$$g_{ds} = \frac{\partial I_{DS}}{\partial V_{DS}} = \mu_n C_{ox} \frac{W}{2L} (V_{GS} - V_{tn})^2 \lambda = I_{DS} \frac{\lambda}{(1 + \lambda V_{DS})} \approx \lambda I_{DS}$$

lin.

$$\frac{\partial I_{DS}}{\partial V_{DS}} = \mu_n C_{ox} \frac{W}{L} \left[(V_{GS} - V_{tn}) - V_{DS} \right]$$

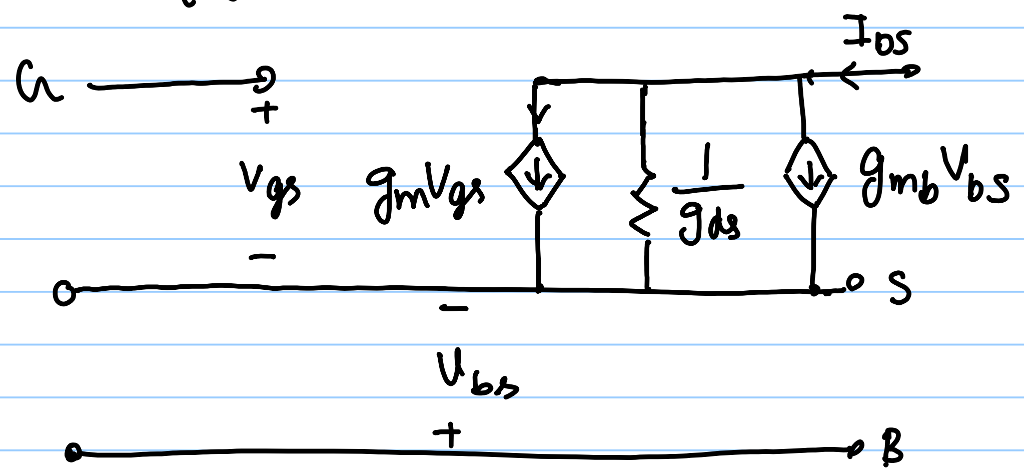


Sat:

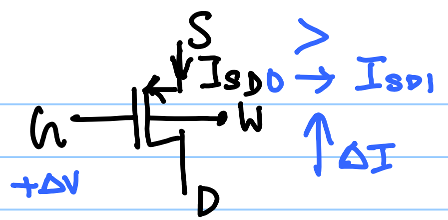
$$g_{mb} = \frac{\partial I_{DS}}{\partial V_{BS}} = \underbrace{\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{th})(1+\lambda V_{DS})}\left(\frac{-\partial V_{th}}{\partial V_{BS}}\right)$$

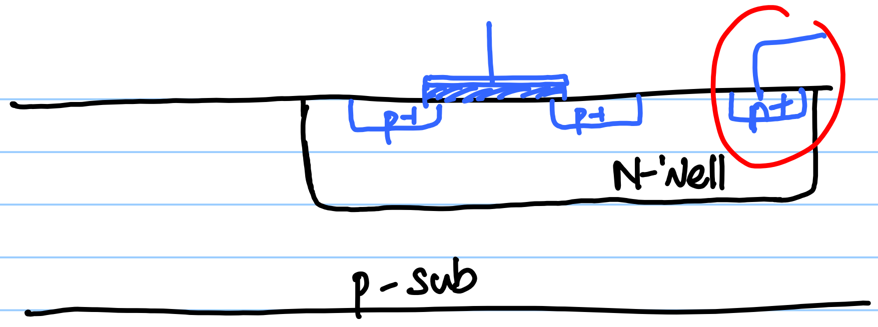
$$= g_m\left(\frac{-\partial V_{th}}{\partial V_{BS}}\right)$$

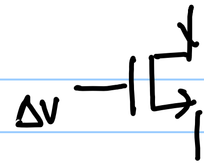
$$= \eta\, g_m$$



DC Small Signal Model.



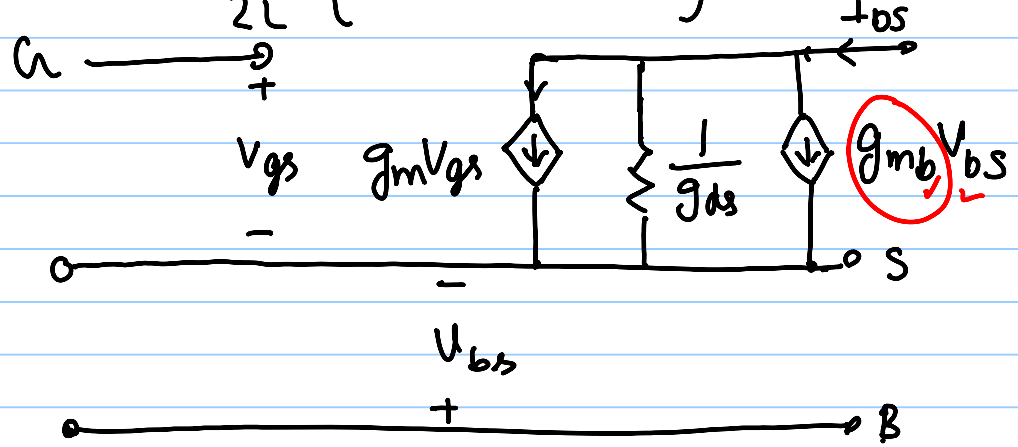




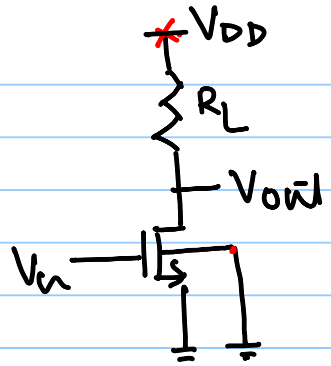
Cut-off: $V_{SG} - |V_{thp}| < 0$, $I_{SD} = 0$

linear: $I_{SD} = \mu_p C_{ox} \frac{W}{L} \left[(V_{SG} - |V_{thp}|) V_{SD} - \frac{V_{SD}^2}{2} \right]$, $V_{SD} < (V_{SG} - |V_{thp}|)$

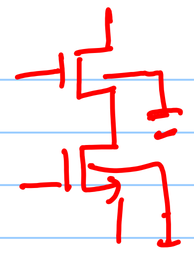
Sat: $I_{SD} = \frac{\mu_p C_{ox} W}{2L} \left[V_{SG} - |V_{thp}| \right]^2 (1 + \lambda V_{SD})$, $V_{SD} \geq V_{SG} - |V_{thp}|$

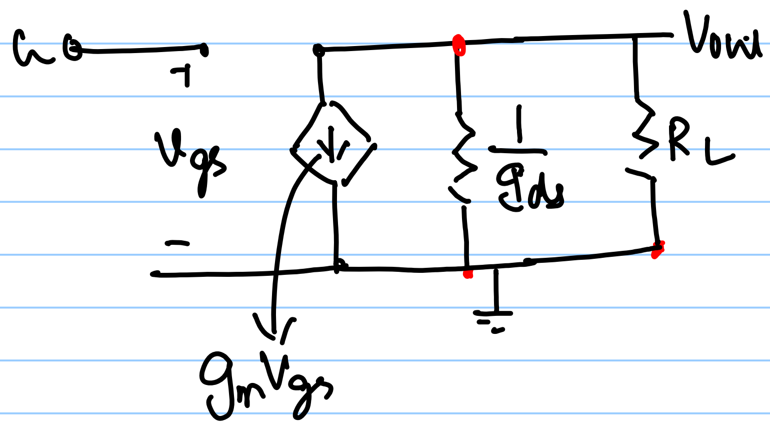


DC Small Signal Model.

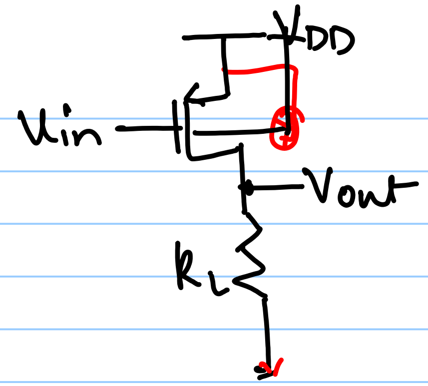


V_{DD}
R_L
V_{out}
V_{in}

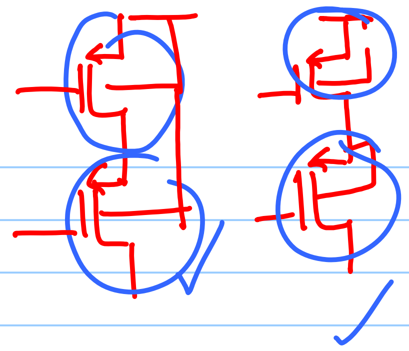


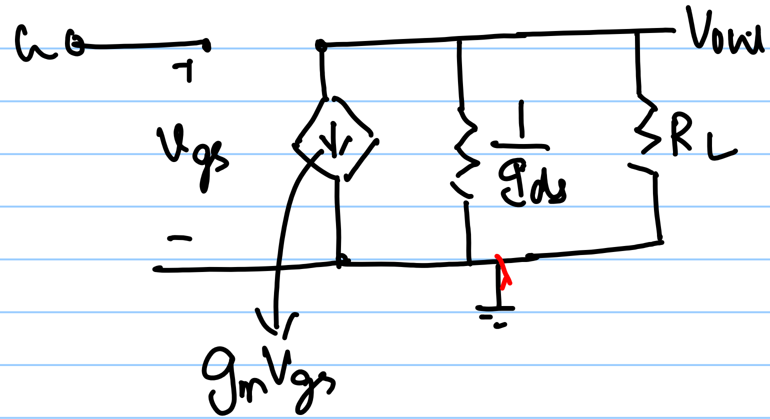


in
+
V_{gs}
−
$g_m V_{gs}$
$\frac{1}{g_{ds}}$
R_L
V_{out}



V_{DD}
V_{in}
V_{out}
R_L





in
+
V_{gs}
−
$g_m V_{gs}$
$\frac{1}{g_{ds}}$
R_L
V_{out}